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# CAE FOR THERMAL MANAGEMENT OF AEROSPACE ELECTRONIC BOARDS USING THE BETASOFT PROGRAM

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p. 8

## SUMMARY

Aerospace electronic boards require special attention to thermal management due to constraints such as their need to be light, small, and maintain high power densities. Also, cooling is mainly through conductive and radiative modes with minor or negligible convective cooling. Due to these particular requirements, thermal design has become an integrated part of the electronic design process in order to avoid expensive repeat prototyping and to ensure high reliability.

To achieve high speed simulations, the BETAsoft code uses semi-empirical formulations and an advanced finite difference scheme that incorporates local adaptive grids. Detailed conduction, convection and radiation heat transfer is considered. Various benchmark verifications of the software simulation compared to infrared images typically prove to be within 10% of each other.

The thermal analysis of a sample avionic card in a natural convection environment is shown. Then, the individual effects of attaching metal screws to the casing, increasing radiative emissivities of the casing, increasing the conductance of the wedge lock, adding an aluminum core to the board, adding metal strips in board layers, inserting conduction pads under components, and adding heat sinks to components are demonstrated.

## INTRODUCTION

With the trend of higher clock speeds and decreasing package sizes, the power density of electronic boards have increased continuously in the last two decades (1). Higher board power densities lead to higher component junction temperatures. Since the failure rates of junctions generally increase exponentially with their temperatures (2), thermal control thus becomes critical in achieving acceptable product reliability. Presently, more than half of electronic failures are due to thermal problems. Thermal management has has become an ever increasing concern of today's electronic designs.

Compared to the majority of electronic applications, those of the aerospace industry present unique thermal concerns due to their environment and resulting modes of heat transfer. Lower pressure leads to decreased convective flow and an increased need to effectively use conductive and radiative cooling. Furthermore, testing aerospace boards is usually difficult in terms of simulating the environment at reduced atmospheric pressures.

Due to the advances in numerical computations, thermal analysis software has become the best solution for electronic designers. Thermal software lowers design cost by

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reducing the load of laborious prototyping tests. The thermal analysis results also provide far more detailed technical information than the tests which are limited by the instrumentation. Typically, software results include a temperature map and gradient of the entire board as well as the individual casing and junction temperatures of every part. Due to the speed software simulation, a significant amount of time is saved. This allows for further examination of alternatives and shortens the time to market. As a result, thermal analysis software is generally regarded as an integrated CAE tool with electronic CAD software today.

Among the thermal analysis tools, two types of software are available: general and specialized. Any general purposed heat transfer or CFD program can be used to simulate the thermal performance of electronic boards. This general software, however, suffers on the aspect of user friendliness. It is time consuming to set up a board or move a component using any general purpose finite element program. This, in turn, prohibits the effective analysis of a real board containing more than 20 components.

Specialized thermal software imports the board layout directly from CAD systems. User-friendly menus to allow for modifications of the board with only a couple key strokes and for quick and easy variation of the thermal environment. This allows for the setup time to shorten to a couple hours and with alternative results obtained in a only few minutes. Since thermal design generally requires an iterative process, this specialized software is the standard tool used in electronic designs today.

The objective of this paper is to describe a unique semi-empirical approach to thermal analysis which provides fast computation and high accuracy. This thermal software, BETAsoft-Board, is used to illustrate the applications of a typical aerospace board in terms of various parametric effects of design solutions and alternatives. Comparative advantages of these alternatives are discussed and the results of their combined used as design solutions are presented.

## NUMERICAL MODELING

A straight forward approach of thermal analysis is to use the finite element scheme for conduction and the Navier-Stokes equations for convection. Although this is the approach used by many heat transfer programs, the obvious draw-back is the large memory requirement and substantial computational time involved. This excludes the use of PCs for sophisticated thermal designs.

A unique approach developed by Dynamic Soft Analysis, Inc. is the use of a modified finite difference scheme for conduction and semi-empirical based equations for convection. Significant effort has been devoted to this development. The end result is a fast yet accurate thermal analysis. Since the equations involved are numerous, only a brief summary of the modeling approach is described below.

### Conduction:

Standard heat conduction equations are used in the computation (3). Finite difference grids with local properties are applied to the board. Along the board edges, heat transfer to wedge locks is implemented. Up to three physical board layers can be considered. The components interact with the board through the individual leads as well as through the gap beneath a component. The board layers can be nonhomogeneous by specifying local regions of varying volumetric fractions of metal. Furthermore, the conductivities along the x and y directions of the board can be altered in localized regions of each layer.

Since the components can be set on either side and any location on the board, the modeling of conduction to the board is implemented through the use of locally refined adaptive grids. Only at the locations where grid refinement is needed, further grids are automatically generated. This scheme enhances the accuracy significantly while only slightly increasing the computational burden.

### Convection:

Three dimensional flow effects and thermal fields are considered in the convective modeling. Although the experimental results and data correlations are well reported for 2 dimensional configurations (4), the consideration of detailed three dimensional effects takes substantial effort. Vast amounts of literature on various data and correlations were reviewed. It was found that frequent discrepancies appeared. As a result, a large amount of in-house wind tunnel tests using various boards from regular arrays to irregular arrays of components were conducted. Infrared results of components and boards were obtained to check with the existing correlations and to create a new set of correlations. To cover a large number of variations, more than 40 equations are employed.

For each component, the different heat transfer from each exposed side is calculated based upon its local flow and thermal environment. The convective heat loss from the leads is modelled. The effects of flow diversion, thermal boundary layer, heat sink fins, and adjacent boards or casings are also considered. Natural convection can be calculated. When there is forced convection, the combined convection is considered.

### Radiation:

Radiation is very important in aerospace applications. The surface emissivities of individual components and of the boards can be assigned. The radiation between the components and the board underneath is precisely modeled in the computation. The radiation between a component and the opposite board is closely simulated. Lastly, the minor radiative interaction with adjacent components is approximated.

### Integration:

Both the geometric configuration and thermal environment of the board are tightly integrated with other CAD and CAE programs. The BETAsoft-Board program interfaces with more than 20 different CAD placement programs to transfer the board layout directly into the board thermal analysis, saving a significant amount of set up time. The thermal environment of the board can be transferred from the BETAsoft-System program which determines the incoming air velocity and temperature as well as the spacing and conditions of adjacent boards. BETAsoft-Board solves for the detailed thermal environment of each individual component. This information can be transferred to the BETAsoft-Component program for an in-depth component packaging analysis.

Furthermore, the junction temperatures from the Board thermal analysis interface to popular reliability analysis programs. This later allows for a very accurate reliability report.

## RESULTS AND DISCUSSION

The BETAsoft-Board program has been in existence and under constant improvement for more than 7 years. Hundreds of leading companies worldwide use BETAsoft as an integral part of their design process. From the large number of comparisons with in-house and users' tests, an error range of within 10% has been generally observed. This includes computer mother boards, military backpacks, avionic boards, satellite boards, industrial control boards, etc. for a wide range of operational conditions. A typical infrared comparison is shown in Fig. 1 and data comparison in Table 1.

To illustrate thermal management techniques, an avionic board case is considered. The board layout has been automatically transferred from PCAD. As shown in Fig. 2, the transformer has a power of 3 watts; and the components along top edge of board and one near the bottom middle are 1 watt each. All of the remaining components are low power.

For this case, the environment conditions were an ambient temperature of 30°C and natural convection at .9 atmospheres of pressure. The objective of the present thermal design is to make sure all component casing temperatures are under 95°C to achieve the overall reliability requirements.

For this board in a natural convective environment, the casing temperatures of the transformer and 3rd component in at top are 184.6°C and 139.6°C, respectively. The computation time for this board is only 3 minutes on the PC platform and less than 1 minute on the workstation. The temperature contour is shown in Fig. 3 and the component temperatures are shown in Fig. 4. Some thermal design considerations to reduce the component casings in excess of 95°C are exercised in the following parametric studies:

### Screws Attached to the Case:

A very common situation is the attachment of the board to the cold casing with screws. Five screws are used, each has a thermal resistance of 60°C/Watt. The sink temperature is at 30°C. The resulting temperature of the two components are 172.9 and 133.7°C respectively for the transformer and component CR25.

### Surface Emissivities:

Since the board is hot and the case is cool (at 30°C), it is possible that the radiative heat loss can be increased by changing the inner casing emissivity from 0.05 (a bright metal) to 0.8 by applying an organic coating. The resulting temperature reduction is from 172.9°C to 125.0°C for the transformer and from 133.7 to 112.9°C for CR25.

As expected, surface emissivity plays an important role, especially for a hot board in a naturally convective environment. Plus, the change from .05 to .8 is a large magnitude for emissivity.

## Wedge Lock Resistance:

The thermal resistance of the wedge lock can be varied. Changing the thermal resistance from 1 to .2 (°C inch/Watt) reduces the temperatures of the transformer from 125.0 to 123.7°C and CR25 from 112.9 to 108.5°C. There are some minor effects but they are not substantial for this range of resistance. Whether a wedge lock exists or not would have substantial effects.

## Metal Core:

A very common approach is to add a metal core to the board. An aluminum metal core of .01" thickness has been applied to bring the heat from the hot components to the wedge lock. The results (with the new wedge lock resistance) show reduction of the temperatures of the transformer from 123.7 to 93.1°C and CR25 from 108.5 to 75.6°C. This appears to be a very effective means to cool the board.

## Local Metal Strips:

For space applications, the weight of the board is very important. The aluminum core is effective but adds a lot of weight. An alternative is to use only strips of metal core to bring heat from the high power components to the wedge lock. The is done as shown in Fig. 5. The resulting temperature increases slightly from 93.1 to 99.9°C for the transformer and from 75.6 to 76.9°C for CR25. However, the weight of the strips are only 12% of the metal core.

## Conduction pads:

Although the local board temperature has been reduced, the temperature of the hot components are still much higher than the board. This is because the high thermal resistance between the component and the board. This usually occurs when the component leads are few and thin while a gap exists underneath the component. This gap serves as a thermal resistance. To reduce this resistance, conduction pads (with conductivity .22 W/°C m) have been installed between the high power components and the board.

The resulting temperatures of the transformer and the CR25 are 84.7 and 61.2°C, respectively. Thus the addition of conduction pads have resulted in a significant temperature drop.

## Heat Sink on Component:

The top row of 1 watt parts and the transformer are now within the desired range. However, the 1 watt part at the bottom edge is still well above the allowed value. A final resolution is the addition of a heat sink on top of this hot IC component. Since this part is located at the lower edge where it would be hard to be cooled with a metal strip to the top edge, a pin-fin heat sink is added to its top. As indicated by the manufacturer's catalog, this sink has a thermal resistance, Theta-sa, of value 6 °C/Watt at 3 ft/s air velocity and 3 °C/Watt at 10 ft/s velocity. The resulting temperature of this component is reduced from 107.6 to 69.9°C.

The overall temperature profile of the board is shown in Fig. 6. The resulting component temperatures are shown in Fig. 7. There are no parts beyond the desired values in the component map. The thermal design is now successful.

## CONCLUSION

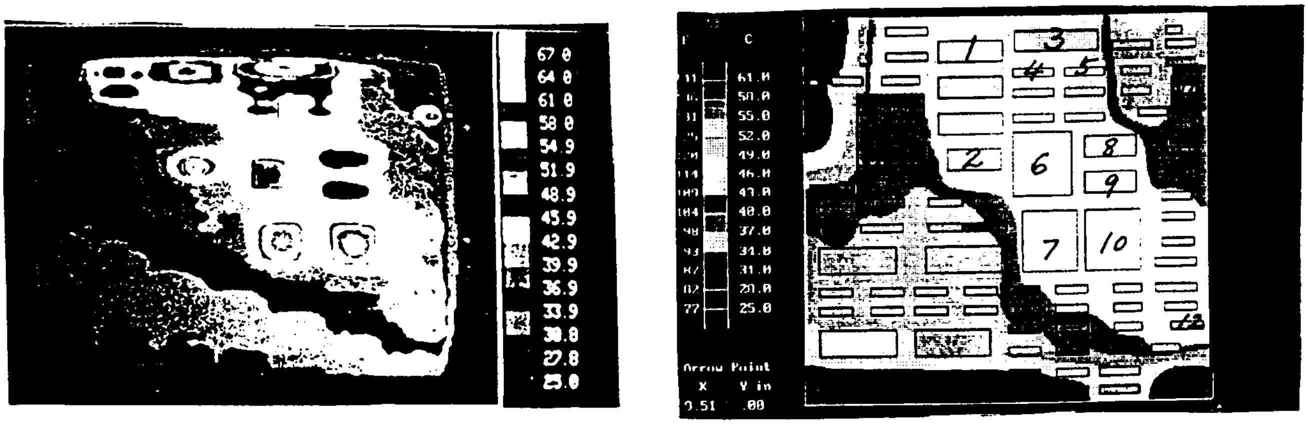
Aerospace electronic boards present special needs for thermal management. Although "general purpose" heat transfer programs may be used for thermal design, they typically are not user friendly and efficient since thermal is not their main function. "Specialized" thermal analysis software is effective because it is designed exactly for that one function. Also, the available integration to board layout, system thermal analysis, component thermal analysis, and reliability analysis software is an important consideration for concurrent engineering.

An unique approach using finite difference and semi-empirical formulations are demonstrated through the BETAsoft-Board program. This approach provides a fast computation while maintaining accurate solutions.

For aerospace thermal designs, the combined use of emissivities, wedge lock resistance, metal strips, conduction pads etc. allows for an effective thermal control which leads to high reliability of the products.

## REFERENCES

1. Oktay, S.; Hannemann, R.; and Bar-Cohen, A.: "High Heat from a Small Package", Mechanical Engineering, March 1986, pp. 36-42.
2. MIL-HDBK-217, Naval Publications and Form Center, Philadelphia.
3. Carslaw, H.S.; and Jaeger, J.C.: Conduction of Heat in Solids, Oxford Press, 1967.
4. Moffat, R.J.; Arvizu, D.E.; and Ortega, A.: "Cooling Electronic Components: Forced Convection Experiments with an Air-Cooled Array", Heat Transfer in Electronic Equipment, ASME.HTD, Vol. 48, pp. 17-27, 1985.



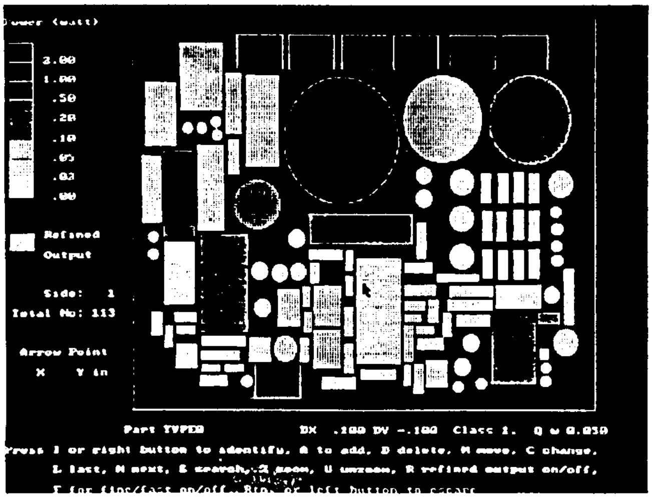
a. Infrared

Figure 1

b. BETAsoft

Table 1

| Component # | Infrared | BETAsoft |
|---|---|---|
| 1 | 54.6 | 56.3 |
| 2 | 49 | 48.5 |
| 3 | 52.5 | 51.5 |
| 4 | 50.5 | 48.9 |
| 5 | 47.5 | 46.6 |
| 6 | 46.0 | 46.9 |
| 7 | 48.9 | 46.2 |
| 8 | 47.5 | 48.3 |
| 9 | 47.5 | 49.2 |
| 10 | 48.9 | 48.7 |
| 11 | 47.5 | 45.1 |
| 12 | 50.5 | 50.5 |



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L last, N next, S search, Z zoom, U unzoom, R refined output on/off,

Figure 2

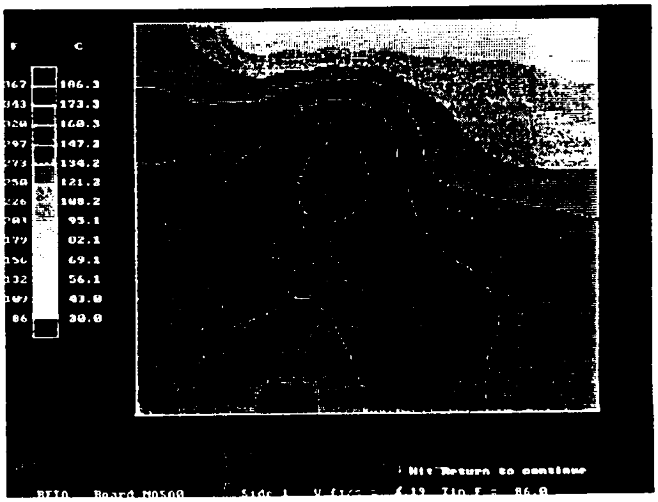

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Figure 3

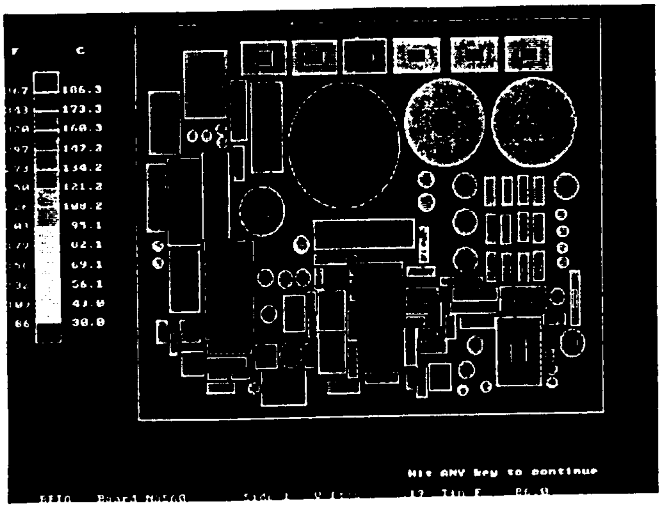

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Figure 4

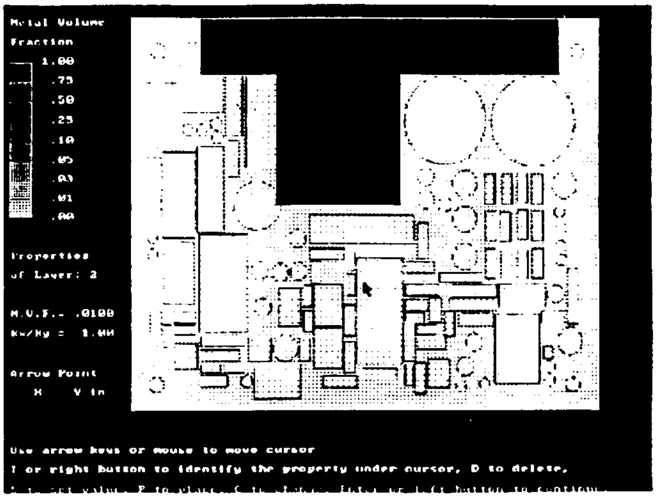

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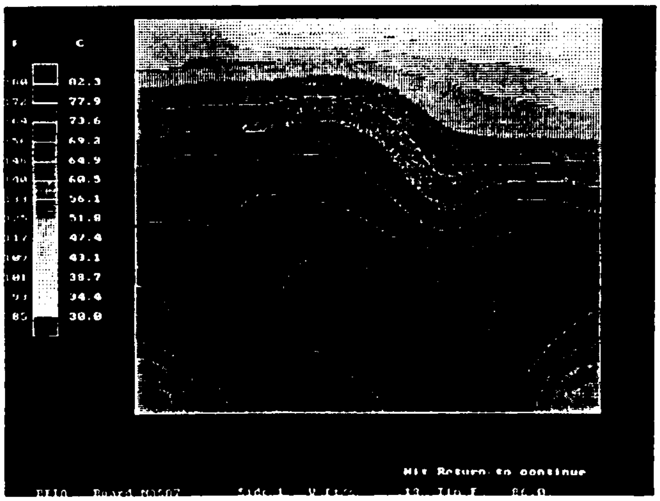
Figure 5



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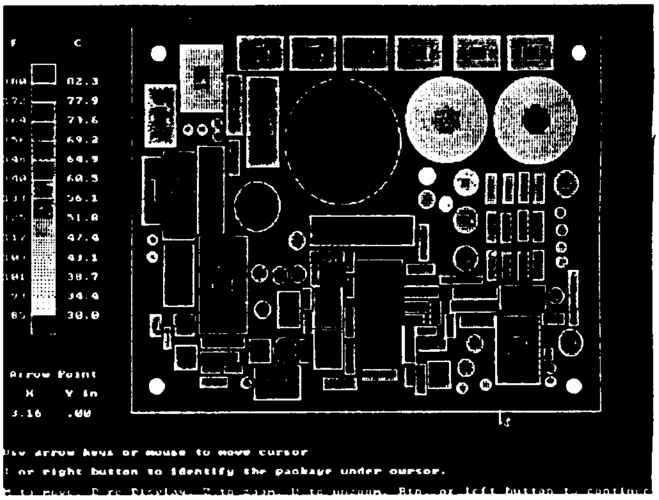

Arrow Point
X Y in
3.16 .00

Use arrow keys or mouse to move cursor
I or right button to identify the package under cursor.

Figure 7

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